Having filled a fresh tube with fresh spun glass, I carefully exhausted with the Sprengel pump on January 24th, and the exhaustion was kept up till February 5th, that is, for twelve days. During this time I frequently tested with the McLeod gauge. A very slight increase of pressure was found during that interval; but it was so slight that I am not able to say that it was greater than that which is observed at all times, even with the Sprengel pump in excellent order, when a vacuum is maintained for several days.

On February 5th, I passed three or four bottlesful of mercury through the pump, and had a vacuum of about 0·5 **M** as shown by the McLeod gauge. I then applied heat, and had instantly an abundance of gas given off from the spun glass. This was collected as before, and analysed.

The number of glass fibres was 15,500, giving an estimated surface area of 3527 sq. centims. The amount of gas given off was 0·41 c.c.; which is considerably less in proportion than in my first experiment.

Of this gas it was found that 78·6 per cent. was carbonic acid gas (absorbable by caustic potash). Of the remainder 10·5 per cent. was oxygen (absorbed by pyrogallic acid and potash); while 89·5 per cent. was left unabsorbed; and may be supposed to be mainly nitrogen.

The very large proportion of carbonic acid gas is remarkable, and it is difficult to account for, unless we may suppose that it was taken up by the glass in large quantity during the operations of drawing out the glass into fibres, and enclosing it in the containing tube—operations during which there was, in these preliminary experiments, an abundant supply from the blowpipe flames.

II. "On Underground Temperatures, with Observations on the Conductivity of Rocks, on the Thermal Effects of Saturation and Imbibition, and on a special Source of Heat in Mountain Ranges." By JOSEPH PRESTWICH, M.A., F.R.S., Professor of Geology in the University of Oxford. Received January 24, 1885.

(Abstract.)

The author remarks on the difference of opinion between physicists and geologists respecting the probable thickness of the outer crust of the earth—the former, on the strength of its great rigidity and the absence of tides, contending for a maximum thickness and comparative solidity of the whole mass; while the latter, in general, on the evidence of volcanic action, the crumpling and folding of the strata in mountain ranges, its general flexibility down to the most

recent geological times, and the rate of increase of temperature in descending beneath the surface, contend for a crust of minimum thickness as alone compatible with these phenomena.

The question of underground temperature, which is a subject equally affecting the argument on both sides, had engaged the author's attention in connexion with an inquiry respecting volcanic action, and he was induced to tabulate the results to see how far the usually received rates of increase were affected by various interfering causes—not that most of them had not received due attention, but it was a question whether sufficient allowance had been made for them.

Although Gensanne's first experiments were made in 1740, and others were subsequently made by Daubuisson, Saussure, and Cordier, in coal and other mines, it was not until the construction of deep artesian wells commenced in the second quarter of this century, and Walferdin introduced his overflow thermometer, and precautions were taken against pressure, that the more reliable observations were made and admirably discussed by Arago. The Coal Commission of 1866 collected a mass of important evidence bearing on the question, and in 1867 a Committee of the British Association was appointed to collect further information. Under the able superintendence of Professor Everett, a series of valuable experiments with improved instruments has been made, and full particulars published in the Annual Reports of 1868—1883.

But notwithstanding the precautions taken, and the accuracy of the experiments, they present very wide differences in the thermometric gradient, ranging from under 30 to above 120 feet per degree Fahr. Consequently different writers have adopted different mean values. On the Continent one of 30 metres per degree C. has been commonly adopted, while in this country some writers have taken a mean of 50 feet per degree, and others of 60 feet or more. The object which the author has in view is to see whether it is not possible to eliminate the more doubtful instances, and to bring the probable true normal gradient within narrower limits. In so doing he confines himself solely to the geological side of the inquiry.

In a general list, Table I, he gives all the recorded observations in the order of date. The list embraces observations at 530 stations in 248 localities. The most reliable of these he classifies under three heads, in Tables II, III, and IV.

1. Coal mines.
2. Mines other than coal.
3. Artesian wells and bore-holes.

To which tunnels are added in a supplement.

The author then proceeds to point out that the gradients given in many of the earlier observations were wrong in consequence of neglecting the height of the surface, and from the exact mean annual

temperature of the locality not being known. They also differed amongst themselves from taking different surface temperatures, and starting from different datum levels. To these he endeavours to assign uniform and corrected values.

The essential differences in the results in the several tables depend, however, upon dissimilar geological conditions, which unequally affect the conductivity of the strata, and disturbing causes of different orders. In the mines the latter are—

1. The currents established by ventilation and convection.
2. The circulation of underground waters.
3. Chemical reactions.
4. The working operations.

And in artesian wells—

1. The pressure of the water on the thermometers.
2. Convection currents in the column of water.

In the later experiments pressure has been thoroughly guarded against, but against the subtle influence of the other causes, though long known, it is more difficult to guard.

Coal Mines.—The author then proceeds *seriatim* with each subject, commencing with coal mines. In these he shows that ventilation and convection currents have rendered many of the results unreliable, as he shows to have been the case in the well-known instance of the Dukinfield coal pit. The circulation of air in coal pits varies from 5000 to 150,000 cubic feet per minute, and tables are given to show how this variously affects the temperature of the coal at different distances from the shaft *though on the same level.* As a rule, the deeper the pit the more active is the ventilation, and therefore the more rapid the cooling of the underground strata. In some pits the in-draughted air has been known to form ice, not only in the shaft, but icicles in the mine near the shaft.

The cooling effects of ventilation are shown to begin immediately that the faces of the rock and coal are exposed, and as the hotter (and deeper) the pit, and the more gassy the coal, the more active is the ventilation, so these surfaces rapidly undergo a cooling until an equilibrium is established between the normal underground temperature and the temperature of the air in the gallery. Judging by the effects of the diurnal variations on the surface of the ground, it is clear that when there is a difference of 10° to 12° or more between the air in the gallery and the normal temperature of the rock, an exposure even of a few days must tell on the surfaces of both coal and rock to the depth of the 3 to 4 feet—the usual depth of the holes in which the thermometers are placed. The designation of "fresh open faces" is no security, as that may mean a day or a week, or more. The author considers also that so far from the length and permanence of the experiment affording security, he is satisfied

on the contrary that those experiments in which it is stated that the thermometer has been left in the rock for a period of a week, a month, or two years without any change of temperature, affords *primâ facie* evidence of error, inasmuch as it shows that the rock has so far lost heat as to remain in a state of equilibrium with the air at the lower temperature in constant circulation.

Another cause of the loss of heat which requires some notice is the escape of the gas, which exists in the coal either in a highly compressed, or, as the author thinks more probable, in a liquid state. A strong blower of gas has been observed to render the coal sensibly cooler to the touch. In another case whereas the temperature of the coal at the depth of 1269 feet was 74° F., at the greater depth of 1588 feet in a hole with a blower of gas it was only 62°. One witness observed that "the coal gives out heat quicker than the rock." There is generally a difference of 2° or 3° between the two.

On the other hand, the coal and rocks when crushed and in "creeps" acquire a higher temperature owing to the liberation of heat by crushing.

The effects of irregularities of the surface on the underground isotherms, although unimportant in many of our coal-fields, produce very decided results in the observations on the same level in the mines among the hills of South Wales. Sections are given to show how the temperature rises under hills and falls under valleys, showing that it is often essential to know not only the depth of the shaft but the depth beneath the surface at each station where the experiments are made.

The author therefore considers that to assign a value to an observation we should know—1. Height of pit above sea level. 2. The exact mean annual temperature of the place. 3. Depth beneath the surface of each station. 4. Distance of the stations from the shaft. 5. Temperature and columns of air in circulation. 6. Length of exposure of face. 7. Whether or not the coal is gassy. The dip of the strata and the quantity of water are also to be noted.

Very few of the recorded observations come up to this standard, and the author has felt himself obliged to make a very restricted selection of cases on which to establish the probable thermometric gradient for the coal strata. Amongst the best observations are those made at Boldon, North Seaton, South Hetton, Rosebridge, Wakefield, Liége and Mons. These give a mean gradient of $49\frac{1}{2}$ feet for each degree F. The bore-holes at Blythswood, South Balgray, and Creuzot give a mean of 50·8 feet.

Mines other than Coal.—The causes affecting the thermal conditions of these mines are on the whole very different to those which obtain in coal mines. Ventilation affects both, but in very unequal degrees. In mineral mines it is much less active, and the cooling effects are

proportionately less. On the other hand the loss of heat by the underground waters in mineral mines is very important. In some mines in Cornwall, the quantity of water pumped up does not exceed 5 gallons, while in others it amounts to 200 gallons per minute. The Dolcoath mine used to furnish half a million gallons of water in the twenty-four hours, while at the Huel Abraham mine it reached the large quantity of above 2,000,000 gallons daily. The rainfall in Cornwall is about 46 inches annually, and of this about 9 inches pass underground. In the Gwennap district, where 5500 acres were combined for drainage purposes, above 20,000,000 gallons have been discharged in the twenty-four hours from a depth of 1200 feet. This water issues at temperatures of from 60° to 68°, or more than 12° above the mean of the climate, showing how large must be the abstraction of heat from the rocks through which the waters percolate.

Hot springs are not uncommon in these mines. They are due to chemical decomposition, and to water rising in the lodes and fissures from greater depths. The decomposition which goes on in the lodes near the surface, and whereby the sulphides of iron and copper are reduced ultimately to the state of peroxides and carbonates of those metals, is a permanent cause of heat, especially apparent in the shallower mines. On the other hand, where the surface waters pass rapidly through the rocks, they lower the temperature, and give too low readings.

While ventilation, therefore, reduces the rock temperature, the water which percolates through the rock, and more especially through the veins and cross-courses, sometimes raise, and at other times lower the temperature of the underground springs. Mr. Were Fox, who for many years made observations on the underground temperature of the Cornish mines, gave the preference to the rocks, while Mr. Henwood, an observer equally experienced and assiduous, considered that the underground springs gave surer results. Both were of course fully alive to all the precautions that in either case it was necessary to take to guard against these causes of interference.

Taking ten of the most reliable of Mr. Henwood's observations at depths of from 800 to 2000 feet, the mean gives a thermometric gradient of 42·4 feet per degree, but Mr. Henwood himself gives us the mean of 134 observations to the depth of 1200 feet, a gradient of 41·5 feet to the experiments in granite, and of 39 feet to those in slate.

Taking the experiments of Mr. Fox in eight mines, varying in depth from 1100 to 2100 feet, the mean of the experiments made in the rock give a gradient of 43·6 feet per degree. The mean of the two observers give a gradient of 43 feet per degree.

For the foreign mines, in the absence of fuller data, and especially failing in information of the depth of the station beneath the surface,

which in the hilly district of Freiberg and Hungary introduces an element of great uncertainty, it is impossible to arrive at any safe conclusion.

Artesian Wells and Borings.—This class of observations presents results much more uniform, and whereas the mines observations were made, the one in crystalline, and the other in unaltered palæozoic rocks, the wells are, with few exceptions, in the softer and less coherent rocks either of Cretaceous, Jurassic, and Triassic age, which are much more permeable, and, as a rule, much less disturbed.

The causes of interference are mainly reduced to pressure on the instruments and convection currents. The early experiments, where no precautions were taken against these, are, with few exceptions, unreliable, and must be rejected. The larger the bore-hole the greater the risk of convection currents, and Professor Everett has shown that in many cases of deep and large artesian borings, the water which lodges in them is reduced to a nearly uniform temperature throughout the whole depth by the action of these currents. In the deep boring at Sperenberg, before the introduction of plugs to stop these currents, it was found that the temperature near the top of the bore was rendered 4·5° F. too high, and at the bottom at a depth of 3390 feet, 4·6°, if not 6·7°, too high by the currents.

Taking the bore-holes in which the water does not overflow, and where, owing to the precautions against these sources, such as those of Kentish Town, Richmond, Grenelle, Sperenberg, Pregny, and Ostend, we get a mean gradient of 51·9 feet per degree.

Overflowing artesian wells should, if we were sure of all the conditions, give the best and most certain results. Taking those where the volume of water is large, and the observations made by competent observers, as in the case of the wells of Grenelle, Tours, Rochefort, Mondorff, Minden, and others, we obtain a mean of 50·2 feet, or taking the two sets of wells, of 51 feet per degree.

The author, however, points out a source of possible error in those wells, arising from a peculiarity of tubage which requires investigation, and owing to which he thinks the water may suffer a loss of heat in ascending to the surface.

With respect to the extra-European wells, more particulars are required. It may be observed, however, that the wells in the Sahara Desert, which were made by an experienced engineer accustomed to such observations, the mean of eleven overflowing wells, at depths of from 200 to 400 feet, gave 36 feet per degree.

Tunnels.—For the Mont Cenis Tunnel, allowing for the convexity of the surface, Professor Everett estimates the gradient at 79 feet, and for the St. Gothard, 82 feet per degree. But Dr. Stapff found in the granite at the north end of the tunnel a much greater heat and more rapid gradient, for which there seemed no obvious explanation.

Though this axis of the Alps is of late Tertiary date, the author points out that it cannot be due to the protrusion of the granite, as the Swiss geologists have shown that the granite was in its present relative position and solidified before the elevation of this last main axis of the Alps, and he suggests that the higher temperature may be a residue of the heat caused by the intense lateral pressure and crushing of the rocks which accompanied that elevation, for in the crushing of a rigid material such as rock, almost the entire mechanical work reappears as heat.

Conductivity of the Rocks. Effects of Saturation and Imbibition.—Some of the apparent discrepancies in the thermometric gradients are no doubt due to differences in the conductivity of the rocks. Applying the valuable determinations of Professors Herschel and Lebour to the groups of strata characterising the several classes of observations, the following results are obtained:—

	Mean conductivity. k.	Mean resistance. r.
1. Carboniferous strata..........	·00488	275
2. Crystalline and schistoze rocks.	·00546	184
3. Triassic and cretaceous strata..	·00235	465

From this it would appear that the conductivity of the rocks associated with the mineral mines is twice as great as that of the artesian wells class. But all the experiments, with the exception of three or four, were made with blocks of dried rocks, and those showed a very remarkable difference; thus, for example, dry New Red Sandstone gave k 0·00250, whereas when wet it was increased to k 0·00600. The author remarks that as all rocks below the level of the sea and that of the river valleys are permanently saturated with water, dry rocks are the exception, and wet rocks the rule in nature, consequently the inequalities of conductivity must tend to disappear. The power of conduction is also greater along the planes of cleavage or lamination than across them, and therefore the dip of the strata must also exercise some influence on the conductivity of different rocks and "massifs." With respect to the foliated and schistose rocks, M. Jannettaz has shown that the axes of the thermic curve along and across the planes of foliation and cleavage, are in the following proportions:—

Gneiss of St. Gothard	1 : 1·50
Schists of Col Voza	1 : 1·80
Cambrian Slates, Belgium	1 : 1·98

This cause will locally affect the rock masses.

Conclusion.—The author deduces from the three classes of observations a general mean thermic gradient of 48 feet per degree Fahr., but

he considers this only an approximation to the true normal gradient, and that the readings of the Coal-mines and Artesian-well experiments are, owing to the causes he enumerates, still too high. He also discusses the question whether or not the gradient changes with the depth. His own reduction of the observations gave no result, but he points out that in all probability the circulation of water arising from the extreme tension of its vapour is stayed at a certain depth; while as it is known experimentally that the conductivity of iron diminishes rapidly as the temperature increases, this may possibly in a different degree apply to rocks. If, therefore, there is any change, these indications would be in favour of a more rapid gradient.

Taking all these conditions into consideration, the author inquires whether a gradient of 45 feet per degree may not be nearer the true normal than even the one of 48 feet obtained by the observations.

III. "On the Connexion between Electric Current and the Electric and Magnetic Inductions in the surrounding Field." By J. H. POYNTING, M.A., late Fellow of Trinity College, Cambridge, Professor of Physics, Mason College, Birmingham. Communicated by Lord RAYLEIGH, M.A., D.C.L., F.R.S. Received January 31, 1885.

(Abstract.)

This paper describes a hypothesis as to the connexion between current in conductors and the transfer of electric and magnetic inductions in the surrounding field. The hypothesis is suggested by the mode of transfer of energy in the electromagnetic field, resulting from Maxwell's equations investigated in a former paper ("Phil. Trans.," vol. 175, pp. 343—361, 1884). It was there shown that according to Maxwell's electromagnetic theory the energy which is dissipated in the circuit is transferred through the medium, always moving perpendicularly to the plane containing the lines of electric and magnetic intensity, and that it comes into the conductor from the surrounding insulator, not flowing along the wire.

Symbolising the nature of the induction by unit tubes drawn in the direction of the induction in the usual way, *i.e.*, so that there is unit quantity of induction over every section of a tube, the electric induction is equal to $K \times$ electric intensity $\div 4\pi$, and the magnetic induction is equal to $\mu \times$ magnetic intensity. The electric induction is the same quantity as Maxwell's "displacement." The hypothesis now made